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DETAILED CONCEPTS IN PERFORMING OVERSIGHT ON AN ARMY RADIOGRAPHIC INSPECTION SITE

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March 2017

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Throughout the federal government and more specifically the Department of Defense, there are an extensive number of facilities that perform various nondestructive tests, inspections, and evaluations. The U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ, generally provides the oversight to ensure these facilities have the correct infrastructure, equipment, personnel, procedures, and documentation in place to conform to nationally recognized standards. This report specifically reviews the radiographic testing method requirements and will discuss and review the concepts for all the subcomponents that should or shall be in place to sufficiently show the site is qualified and certified.

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INTRODUCTION

Throughout the federal government and more specifically the Department of Defense, there are an extensive number of facilities that perform various nondestructive tests (NDT), inspections, and evaluations. These sites may be a combination of government owned and operated, government owned and contractor operated, or full contractor only facilities. In any of these situations, these sites are required to have the correct infrastructure, equipment, personnel, procedures, and documentation in place to conform to nationally recognized standards. The U.S. Army Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, NJ, generally provides the oversight to ensure these requirements are being met and continually practiced on munitions and weapon systems. This report is intended to discuss and review the concepts for all the subcomponents that should or shall be in place to sufficiently show the site is qualified and certified. This report is specifically reviewing the radiographic testing (RT) method requirements.

Most of these subcomponents apply to the other recognized NDT methods (ultrasonic, eddy current, magnetic particle, dye penetrant, etc.), but are slightly different to meet the standards for that direct application. When performing the RT method, the overarching standard that covers the preliminary requirements for personnel, sites, and applying the application is ASTM E 1742 (ref. 1). This document provides additional references depending on if the inspection is film based, digital based, computed tomography (CT), as well as other detailed functions that are part of the RT application. The primary requirements of ASTM E 1742 call out the need to have practices and processes in place to determine: what personnel is qualified or certified, what critical equipment is being used, what processes or procedures are used to repeat the tests, how a given site prepares to meet the part specifications for the customer, and how a site provides continual assurance their process is operating sufficiently. These topics will be detailed throughout this report.

PERSONNEL QUALIFICATIONS AND CERTIFICATIONS

General Overview

The first component that needs to be in place when starting up an NDT inspection site is to have the proper personnel present. This entails having individuals that have a background in the specific NDT method being used, along with additional credentials that justify their appointment to perform any NDT inspection. Within reference 1, the personnel requirement is deferred to various other national standards, such as ASNT SNT-TC-1A, ASNT CP-189, or NAS-410 (refs. 2 to 4). The standard that is selected however has to be agreed upon between the site and the specific customer(s). Some of the personnel qualification and certification standards are more stringent than others, while some recognize certain inspection methods that are not included in others. International facilities often follow the requirements set forth in ISO 9712 (ref. 5), which is generally much more specific in its requirements. However, all the standards require a certified responsible person with specific level III qualifications, certifications, and credentials to oversee the operation.

The responsible level III is then the sole source to develop, maintain, revise, modify, and approve all the procedures for the site's NDT program. This includes the personnel qualifications and certifications document that has to meet the requirements of the national standard selected. Additional duties are to: provide and write the examinations, provide or approve training, ensure all the qualifications are met, approve all certifications for their NDT staff, and track and record all the adjoining information for the program.

Qualifications

The individuals performing a radiographic application have to meet specific levels of education, training, experience, and other tangible assets showing they are competent in the method. The specifications vary slightly on how these levels are defined, but generally, there are three main classification levels. Levels I, II, and III are the ranks that define an individual's skill in the specific inspection method. There is no limit in the number of methods one can practice. However, in practicality, an individual can know a lot of specifics in fewer methods or have a little knowledge across more methods. Generally, four major topics encompass what is included in determining a person's NDT qualifications including training, education, experience, and completed examinations.

Training

The requirements within reference 4 will be used as the general example in this section. Training is a measurement of how many hours of classroom time an individual has spent learning about the specific method(s). To become a level I, the individual must meet the requirements of a minimum of 40 training hours. Level II personnel require an additional 40 hours of more in-depth training, or a total of 80 hours of relevant classroom time. For an individual to meet the level III requirements, no additional training is required, but due to ever changing techniques and technology, a well-rounded level III individual will have several additional training sessions logged. Some of the newest standards or revisions also include additional requirements depending on the sub-method or technique being applied by the practitioner. In the case of RT, if digital methods are being applied, more training is required that should be specific to the sub-method being used [i.e., digital detector arrays, computed radiography (CR), CT, etc.].

Education

The applications of applied radiography can vary significantly. The addition of secondary education such as an associate's degree from a technical school allows an individual to require less training, pending it is in an applicable field of science or engineering. However, some techniques only need a technician type of person who follows a predefined procedure and repeatedly performs a small set of operations. The added need to have additional formal education may not be necessary in that case. On the other hand, some NDT practitioners are involved in CT or research and development. For those areas, additional education would be relevant or necessary in order to understand material sciences, physics, hardware mechanics, software processing, and many other principles in radiography. Generally, a NDT position that holds more responsibility should entail a higher level of education, but the individual should also receive competitive compensation as well. Although there is no specific education requirement for a NDT practitioner, higher education means less up front training is necessary. With education, there is also greater potential for an individual to be a fully functioning certified NDT practitioner that can readily adapt to more specific applications.

Experience

The definition of experience in the field of NDT typically means how much direct hands-on practical time an individual has spent performing specific applications. For the majority of standards, experience is measured in total number of hours spent on the job performing the duties specific to the level of qualification that the practitioner is trying to achieve. Some companies list experience in months or years, which fails the requirement of how experience is tracked. Listing it as a general timeframe leads to suspect questions like "How do you know if the individual actually practiced that method or methods for the entire time?" In some cases, just because someone is with a company for a given period of time does not mean all that time was spent performing direct work in NDT. Although it is a necessary part for a technician type level I or II to clean up the production line or laboratory at the end of a shift, that time should not be counted toward experience unless it is

directly related to applying the NDT method. In some situations, setup and teardown can be counted while in others, it is just a common duty not related specifically to NDT. The responsible level III for the company or site decides what is and is not counted toward experience.

In addition to tracking the number of hours of on the job (OTJ) experience, it is also necessary for the responsible level III to ensure the experience corresponds to the requirements of each qualification level. For radiography, the number of hours varies and is under flux between current and previous revisions of the national standards. Generally speaking, a level I has to acquire between 200 and 400 hours of experience, whereas a level III has to have between 780 and 1600 hours along with a minimum range of years in service, depending on educational background. Some standards allow cross qualifications between NDT methods and allow time to be split in half while others require full time in each method. Depending on the standard in use, different levels of experience can be accumulated for the same level of qualification or certification. In addition, if digital RT methods are being applied, the practitioner should have significant experience documented with the technology and application being used. Further information for performing digital radiography is provided in ASTM E 1255 (ref. 6). Specific applications using detector arrays is provided in ASTM E 2698 and 2597 (refs. 7 and 8). Additional resources are also available through ASTM for CR and CT applications.

Examinations

All the standards referenced in this report require four separate types of examination: a basic or general exam, a specific or method exam, a practical exam, and a physical exam. The physical exam requirements vary from method to method. For RT, an individual must have an unexpired visual eye exam provided by a licensed optometrist/ophthalmologist every year. The practitioner must have or exceed the minimum baseline to ensure a visual impairment does not impact performing duties or interpreting data. In many cases, lifting requirements are not specified in the NDT standards, but that is covered under Occupational Safety and Health Administration documents. The other exams are independently taken, scored, and averaged with an even weight between all three. Typically, the lowest passing score allowed on any one test is 70%, and a composite score of 80% is needed in order to meet the minimum qualification requirement.

The basic or general examination is a test that is designed to cover all the general principles an individual should know. This includes areas on material science, manufacturing processes, information on other NDT methods, and any applicable NDT standard practices. The requirements of this test are common across the standards and typically require no less than 40 questions in a closed book fashion. For the level III qualification, reference 5 requires a minimum of 95 questions which have to cover a certain number of questions in regards to certifying standards, materials and fabrication, and at least 4 separate NDT methods. The questions in the general exam should be scaled to match the expected competency for each level of qualification. This exam is required for each level of qualification to become a level I, II, or III. These exams should also have rotating questions in between recertifications or re-examinations to avoid any individual from getting the same repetitive test.

The specific or method exam covers more detailed questions and situations a practitioner should know for the specific method in which they are seeking qualification or certification in. This exam is typically no less than 30 questions. However, using ISO 9712, the minimum is 50 questions for the level III exam, which has to include a minimum number of questions pertaining to knowledge of the method and its application(s). This exam should also include questions regarding specific part specifications the practitioner may come across at the given site. For the Army, this examine typically also includes areas that cover military specifications of the inspection piece(s) under review. This includes but is not limited to minor, major, and critical defects that impact the function and safety

of the product. This ensures the practitioner understands the NDT method, the parts under examinations, and the dispositioning process too.

The practical exam is a more unconventional test that shows the practitioner can independently perform their duties specific to the level of qualification they are seeking. This exam is generally specified to be a checklist of at least 10 major topics one should know when following the sites NDT procedures. Essentially this exam is a prove-out that the practitioner can take developed instructions and follow them to show they can: setup and perform the inspection correctly, interpret the data according to a specification, and adjust accordingly to the situation provided. Again, this exam should be properly adjusted to match the level of qualification being sought. The level III exam can also include the development of a procedure in place of or in addition to a hands-on test.

Certifications

Simply, to be certified in a NDT method at a certain level, a formal signed document has to be in place showing: the employer recognizes the aforementioned qualifications are met, the responsible level III confirmed the individual has met all the requirements, and signatures of both the responsible level III and a supervisory designee on behalf of the company. Depending on the standard used, a NDT practitioner must recertify every three to five years. Most standards also allow a level III to recertify by showing continuing education and practice in the method through formal papers, presentations, or other technical showings of one's abilities, all of which must be approved by the responsible level III, site, or other certifying body. Table 1 provides an example of a personnel coversheet that provides a complete overview on the qualifications, certifications, and credentials for a NDT practitioner.

Table 1
Example of a NDT personnel's coversheet providing background and credentials

NDT Personnel Certification Cover Sheet:
IOP Document# 0003 Revision A

Name:	
Personnel #/SS:	

*Meets IOP Document# 0001 Rev. A Qualification and Certification of NDT Personnel

	Method	Level	Technique	Date	Comments
Certifications Held:					
*Copies of Cert. are acceptable verification					

	Scores							
	General	Date	Specific	Date	Practical	Date	Composite Score	Comments
Examinations Completed:								
*All exams are kept for record								
*Copies of exams are acceptable								

*IOP= Internal operating procedure

Table 1
(continued)

	Method	Date Valid	Expires	Comments
Date of Certification				
*Valid for 3 years for Level I & II				
* Valid for 5 years for Level III				

	TYPE	Received	Comments
Education			
*Copies of Dipolma or other Formal Certificates are acceptable verification			

	Provider & Instructor	Type	Method	Date	Hours received	Re-Cert. Credits
Training						
*Copies of completed training are acceptable verification						

	Visual Acuity	Color Perception	Comments
Current Results of Vision Test			
* Attached medical form is acceptable verification			
* Valid for 1 year			

	Method	Timeframe	Hours Accumulated	Running Total
NDT Experience				
*OTJ Hours are verified and confirmed by certifing personnel				
*Prior experience must be verified and approved by certifying body				

	Name (Print)		Certification Level	Date
Certifing Person(s) / Level III				
	Signatures			
Acknowledgment of Certification & Qualification				

CRITICAL EQUIPMENT LISTING

Basic Review

The second sub-component that is required as per reference 1 is a complete critical equipment listing. Critical equipment is defined as any physical hardware or software component that can impact, adjust, or affect the image quality in a radiographic setup. In standard practice, one can make a list of every piece of equipment ahead of time that is onsite. From that list, each time a new setup is made, the combined applicable information can be put into one document for record keeping. Some sites may have a fixed pre-built inspection cabinet in which the listing may not change. However, many sites have cross functional setups where sources, image media, shielding, and various other components are interchangeable in order to meet the handling needs of the part and/or to meet the inspection criteria. These listings should include: the operating parameters of each individual component, the make, model, manufacturer, serial numbers, any specialized variables or options each piece may have (i.e., filtration, masking, collimation, scintillator material, etc.), information on any external peripherals (i.e., handling devices, fixturing, etc.), calibration tools, and any verification tools (i.e., defect or master standards, phantoms, etc.). In general, the more information that is recorded the higher level of assurance a customer will have that the equipment will meet the needs of the inspection requirements. This equipment listing also provides a document that ensures repeatability during production and enforces the specific setup and technique being used. In the event a component fails, breaks, or otherwise needs replacement or servicing, the site will have to notify the customer of the change and that a requalification will be required. If the situation arises where a site changes the setup or equipment without a qualification or requalification and customer approval, the site's inspections prior to such would be suspect and likely have to be recompleted. When this occurs, all products up through the last qualification, requalification, and customer approval should be reimaged, interpreted, and dispositioned. Table 2 provides a top level critical equipment listing for a generic setup and technique.

Table 2
Example of a basic critical equipment listing

Critical Inspection Equipment Listing				
Item	M889A1, 81mm Mortar			
Specification	DTL12977143			
	X-ray source	Manufacturer	Model no.	Serial no.
	Linac	Varian	L200AP	AP-1123
Energy / voltage	1 or 2MeV			
Current	n/a			
Dose at 1m (Rads)	0-2800			
Dose Rate at 1m (Rads/min)	10-150			
Trigger (pulses/sec)	50-450			
Internal Filters (thickness / Material)	0.8in Be, 0.12 Cu, 0.05 W			
Spot size (mm)	2			
	Imaging media	Manufacturer	Model no.	Serial no.
	Digital Detector Array (DDA / Flat Panel), aSi type	Perkin Elmer	XRD 1621AN	AACG 110
Pixel Pitch (µm)	200			
Conversion screen	DRZ plus			
Dynamic range (dB)	56100			
Bit depth	16			

Table 2
(continued)

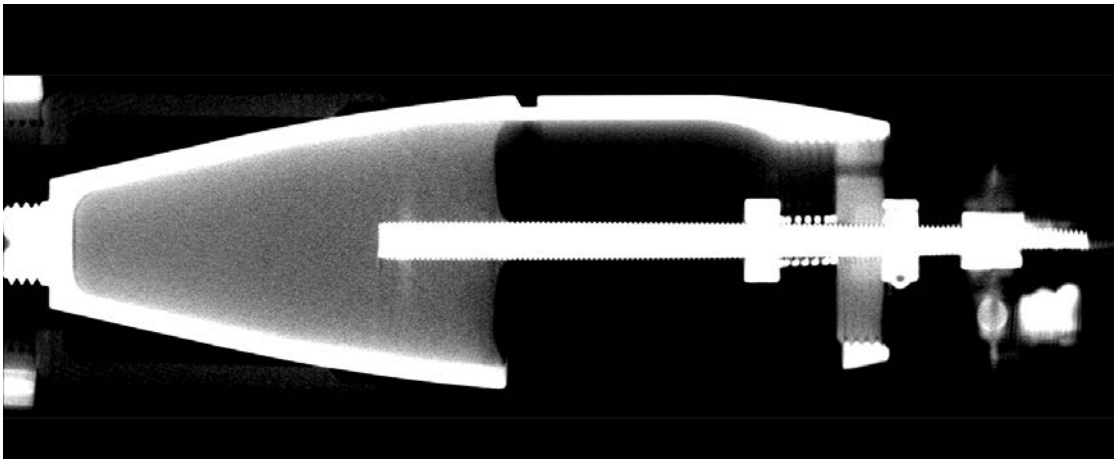
Frame rate (frames / sec)	1-15					
Integration time (sec)	0.1-20					
Detector Area (pixel x pixel)	2048 x 2048					
Masking or shielding	12.5mm W, 12.5 Cu around electronics only					
File formats	.tif, .jpg, .raw, .dcm					
	Product handling system	Manufacturer	Model no.	Serial no.		
	Automated for 81mm	Nekin	ARP2	0001		
	See drawing NekinA1 for details					
	Part Fixtures	Manufacturer	Model no.	Serial no.		
	Aluminum slotted 81mm inserts	ARDEC	AR34P	900993		
	See fixture drawing Pica21D for details					
	Collimation	Manufacturer	Model no.	Serial no.		
	Variable style Lead Plates	Varian	VC5B	VC.1		
Field of view min & max (inch x inch)	1x1, 8x8					
	IQI / RQI	Manufacturer	Model no.	Serial no.		
	81mm Base Gap - 0.03in	ARDEC	M889A1.1	0001		
	81mm longitudinal crack - 0.006in	ARDEC	M889A1.2	0001		
	81mm Porosity Reject	ARDEC	M889A1.3	0003		
	81mm Accept Master	ARDEC	M889A1.4	0002B		
Frequency	All masters prior to start and end of shift					
	See drawing Mil-Dwg-113420 for details					
	Image Acquisition / Review Station	Manufacturer	Model no.	Serial no.	Version Control no.	Time stamp
Acquisition	VI3	VJ Technologies	VI3	ARDEC0.1	3.3.7.3	9/30/2011, 4:26pm
Detailed Version Modifications	Automated Defect Recognition (ADR) package	VJ Technologies	VG4	1.32.4	4.3.2	9/30/2012, 4:27pm
	See attached specifications on ADR algorithm					
External trigger	Exposure synchronization of DDA and Linac	Hampton Systems	001S	34B.4		
	See attached detailed specifications on trigger design					
Review	VI4	VJ Technologies	G6ss$5f	345322	3.55.6.77	10/5/2011, 2:55pm
	See attached detailed manufacturer specifications for software					
PC	E4500	Dell	E4rpp09	FGRRa220	n/a	n/a
Monitor	MaxBrite 4000	Hewlett Packard	MB4A23	5462E	n/a	n/a
Light Meter	Luminosity of STPME phantom image verified monthly	Atla-light	D4w	r33.4	n/a	n/a

Master Defect Standards / Image Quality Controls

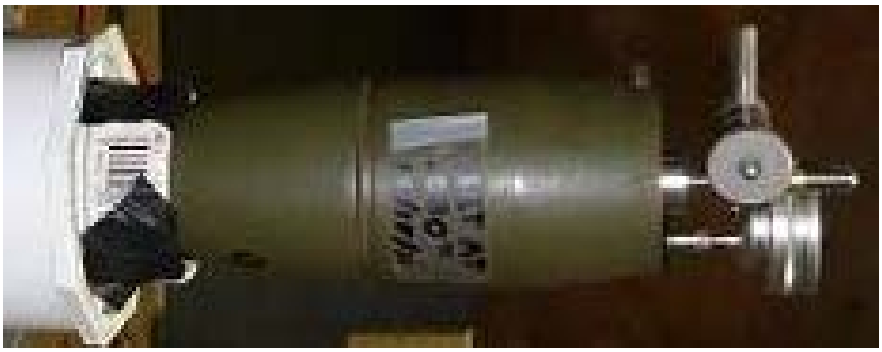
An extension of the critical equipment listing is the need to document, control, and implement specific image quality controls. Depending on the item specification, several options are available to achieve and maintain a specific level of image quality and reliability. The most commonly used image quality indicator (IQI) is the hole type as defined in ASTM E 1025 (ref. 9). These IQIs use a

plaque that is 1 or 2% of the total thickness of the part using an identical material. This IQI also has a series of holes across the plaque that equate to a given percentage of material change within the item. The smaller the hole the higher the contrast and spatial resolution must be in order to discern it in an image. When used with a part of several materials, an equivalent thickness must be calculated to determine what IQI size and material should be used. Internationally, a similar wire IQI is used that determines the same level of image sensitivity. This type of IQI is defined in ASTM E 747 (ref. 10). Instead of detecting a percent change from material missing (i.e., the hole), a wire of the same diameter is present showing the percent change with an equivalent added material. Essentially, they can be thought of as being inverted from one another, but measuring the same characteristics. However, the wire IQI can be more accurate since each IQI has multiple sizes of wire within each set. The wire IQI can specifically control the image quality variations more stringently than the hole type.

However, depending on the inspection part shape, size, and configuration, one type or neither may be applicable or useable. In those situations, a site must defer to using a master standard, defect standard, or representative quality indicator (RQI). In most cases, a part most likely will need a complete set of master standards to encompass all the potential minor, major, or critical defects that can occur during production. The defect standards can be a production sample that has a specific subcomponent removed from its internal configuration. They can be inspection pieces that are armed or in the unsafe position(s) showing an acceptable or rejectable condition. These master standards can be used for go/no-go inspections where the practitioner can easily determine if the system is valid for the detection of simple part presence or safety conditions. In some of the most complex parts, these standards are fully necessary when small or very subtle indications are required to be detected. These master standards are generally manufactured to the given specifications and then used to develop the inspection technique and settings in order to achieve the correct inspection quality. Figure 1 provides a representation of a defect master standard for a 60-mm mortar. The defective condition shown is a 0.03-in. base gap between the explosive simulant and the internal surface of the bottom of the casing (left hand side of figure 1).



(a)
Radiograph



(b)
Photograph

Figure 1
Example of a base gap defect standard for the 60-mm mortar

The key to using IQIs or master standards is to keep very specific documentation. The type, size, material, location, orientation, frequency of use, and other characteristics must be known for repeatability. It should be documented such that another site or user could replicate the controls if needed. The IQIs should be traceable to a known calibration service or supplier. The master standards should conform to detailed drawings of each type and each one verified through the qualification process. In the event any changes are made (i.e., defect master is replaced with another due to being dropped and broken), a requalification of that master or IQI should occur and be accepted by the customer before direct use in production. Since any form of image quality control directly impacts the final output of the inspection, all IQIs and master standards are considered critical equipment and should be included in the overall listing.

Implementation of Defect Standards

Once a technique is complete and the qualification is successful, the masters or IQIs can be implemented on a continuous basis as documented and required. Depending on the product line, the number of potential defects, and the level of criticality of those defects, several different uses can occur. In some situations, the masters or IQIs are imaged at the beginning and end of each shift to verify the inspection quality is maintained for the entire period in between each quality check. In addition to that, other situations may require the need to have the masters or IQIs periodically

imaged for confirmation. This is typically beneficial when imaging large quantities within a given shift or when the cost of the total part inspected is very high. The more quality checks that happen throughout the process, the lower the cost and risk if a quality check is found to be deficient. In that case, all the inspection pieces imaged since the last verification have to be marked suspect and reimaged.

Another example is the need to control the image quality among a large number of image reviewers or practitioners. In order to ensure the image quality is met and to ensure the interpreters are performing adequate reviews, the master standards can be intermittently mixed in with production units. This practice is referred to as "salting," where the masters are salted in at some random interval. During this process, a salter or defect master cannot be missed. All of them must be correctly dispositioned or a deficiency is occurring with either the reader or the image quality. In either case, production must stop and corrective action must be taken to ensure the quality control is meeting the requirements. It is generally understood that the most accurate method of quality control is through the use of master standards because they represent the inspection piece the most accurately.

RADIOGRAPHIC TECHNIQUE

Technique Sheet

Beyond just having a general listing of the equipment specific to each radiographic setup, a detailed technique sheet is required in accordance with reference 1. This sheet takes the critical equipment listing and extends it into the exact physical layout and settings in which the inspection is performed. The general rule in developing a technique sheet is to document enough information so that a common person with basic knowledge in the NDT method can setup the site and equipment in order to replicate or duplicate the given inspection. This is especially important for sites that work with numerous variations of equipment, inspection pieces, and setups. This technique sheet should have very detailed specifics on: the physical location of the critical equipment (i.e., the position of the source, image media, part location, etc.), the exact hardware settings (i.e., energy, current, spot size, etc.), software settings (i.e., integration time, file formatting, digital processing, etc.), part criteria (i.e., specifications, dimensions, orientations, etc.), and equipment positioning (i.e., shooting sketch, dimensions, etc.). The information provided in table 3 shows a general example of a technique sheet. In the case of CT imaging, the technique sheet can get vastly more complex and detailed in order to sufficiently document the setup for repeatability.

Table 3
Example of a general technique sheet for a radiographic examination

[redacted] **Technique Sheet** [redacted]

Item:	120mm Mortar BLA
Date:	28-Feb-13
Customer:	-------
Inspection Method:	Conventional Film - Kodak AA400
Purpose:	To determine if any suspect of defect conditions are present within the melt pour explosive fill.

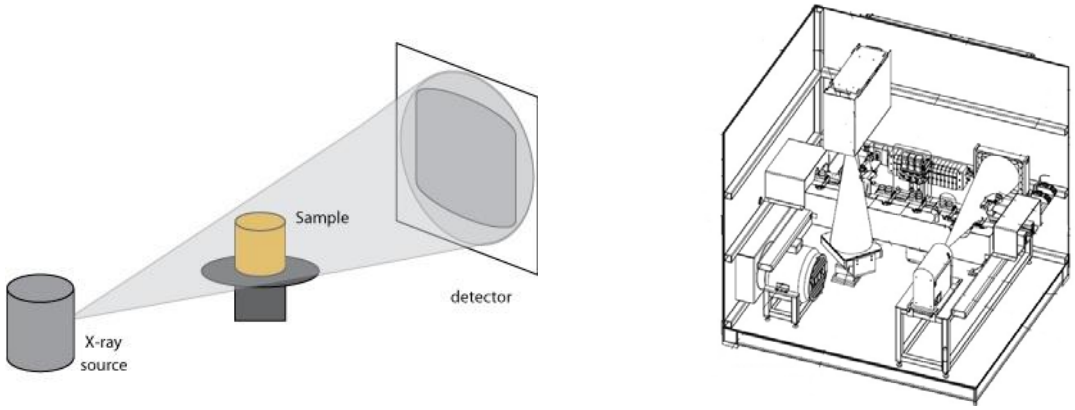
Table 3
(continued)

Part Serial number(s)	1 through 40
Applicable Procedure:	ARDEC SOP: Radiography August 2014, task # 3
Applicable Item Specification:	MIL-C-71134 para 4.5.3
Image Quality Indicators used	2-2T on Fe 2.0, See MIL-C-71134 para 4.5.3.1 for placement
Source used:	Varian 200AP
Image Intensifier Screen(s) used	0.030" Front Lead / 0.010" Back Lead
Cassette Type	Hasley Aluminum Rigidform - Magnesium Face Plates (14"W x 17"L)
Fixture Type	Wood shelf w/hole
# of items per image	2
Energy Setting (keV):	2000
Beam Current (mA):	n/a
Focal spot size setting	2mm
Exposure (mAs) or Dose (Rads):	40
Orientations used	0 & 90-degrees along long axis
Collimation used	none
Digital Detector Array	n/a
Trigger / Pulse rate (per sec.)	n/a
Integration time (µs / fps)	n/a
Pixel size / pitch (µm)	n/a
Field of view (# pixel col. X # row)	n/a
Acquisition / Viewing Software	n/a
Frame Averaging	n/a
Digital filtering	n/a
Detector calibrations	n/a
Contrast to Noise Ratio (CNR) Measured / Required	n/a
Signal to Noise Ratio (SNR) Measured / Required	n/a
Modulator Transfer Function (MTF) in Lp/mm	n/a
Image display	n/a
Saved file format	n/a
Masking used	none

Physical Dimensions / Layout	English Units (inches)	Metric Units (cm)
Source to Object Distance:	67.28	170.88
Source to Imager Distance:	72.00	182.88
Magnification	1.07	1.07
Focal spot size:	0.08	0.20
Geometric Unsharpness:	0.006	0.014
Part thickness:	4.72	12.00

Shooting Sketch

The shooting sketch is a visual representation of the technique, setup, and layout of the inspection. It is an additional supplement that assures the technique is performed consistently during the process. The information on the sketch can vary depending on the complexity of the system and technique. For a conventional film setup, there are not many moving parts that need to be accounted for, but in an automated system, it is hard to portray the layout without a visual photograph or drawing. Figure 2 provides two rudimentary pictures of how a shooting sketch can be represented. Some sites prefer to put the dimensions of the layout directly into the sketch, while others leave all the numerical values directly in the technique sheet. As long as the information is documented in a logical manner, neither practice is incorrect.



(a)
Basic drawing

(b)
Complex setup

Figure 2
Example of a shooting sketch (ref. 11)

QUALIFICATION AND REQUALIFICATION PLANS

The fourth and fifth sub-components called out in ASTM E 1742 are the qualification and requalification plans. A qualification is the process in which a site verifies the setup, procedures, technique, personnel, and that the overall process meets the specifications and requirements of the inspection. The qualification is generally performed once all the subcomponents outlined in reference 1 are completed and approved by the site, the responsible level III, and the customer. The qualification typically has the customer present to avoid any ethical concerns on how it was done and if it was done correctly. The site should prepare a documented detailed plan on how they will prove to the customer that they are ready for production. This plan may include referencing the sites procedures, drawings, instructions, technique sheets, and other documentation. However, it also needs to include: how the qualification will proceed, what inspection samples will be imaged, how many samples will be inspected, how the data will be dispositioned, what constitutes an acceptable qualification, and what will cause an unacceptable qualification. Depending on the inspection parts, some of this criteria is developed from lot sampling plans, risk assessments, and other statistics that will ensure a major or critical defect will not get introduced into the acceptable population of products. There is always a probability an escape will occur. This occurs when a rejectable sample is released as acceptable and can be put into fielded use. In such cases, a malfunction may occur damaging equipment or hurting the users. The qualification should be adequate in order to reduce this probability into a risk acceptance level approved by the customer. Logically, if a site's procedures are well written and organized and they have a competent staff of radiographers, the

process qualification should just follow the instructions from start to finish. The intent is to replicate the exact situation the site will be under when production is being performed.

In general, if the qualification plan is enacted, accomplished, and satisfies the customer and requirements, it is acceptable. If in the event the system under performs, the staff is under experienced or trained, changes are made to the technique or layout, the procedures are not followed, or the image quality or part specifications are not met, the customer should immediately notify the site that the qualification was inadequate, at which time corrective actions should be made and another attempt at qualification can occur. Once an acceptable qualification occurs and production begins, another plan has to be enacted. In addition to the submission of the qualification plan to the customer, a requalification plan should be included. If for any reason a significant change has to be made to the system, equipment, or technique, a requalification may need to occur. A general rule is that if the change may impact the achieved image quality, a requalification should take place.

A requalification is just an extension of a qualification except it occurs once a change is made. For example, if a detector shows signs of degradation and is causing a high number of false rejects (i.e., rejecting good product), the customer or site may decide a change is needed. Once the bad detector is replaced, refurbished, or repaired, additional reassurance is necessary to verify the requirements will continue to be met. Even two identical detectors made consecutively on the same inspection line may respond differently due to the allowable tolerances within the detector itself. The composition of the conversion screen may be slightly different, which may result in a significant difference in exposure time. In any event, a requalification proves that the change was done and all the acceptance criteria is still being met. In some cases, this may lead to adjustments in the technique which then must be documented appropriately. In other instances, the change may not lead to any additional adjustments. Typically, since the technique, procedures, and personnel are proven during the initial qualification, a requalification is not as extensive. This may mean that a smaller number of samples can be inspected to satisfy the customer and requirements. In some of the more advance automated systems, a requalification is identical to the initial qualification to assure the same risk level is achieved. The process and outcome of the requalification then proceeds exactly as the initial qualification did once completed.

OPERATIONAL PROCEDURES

Standard Operating Procedures (SOP)

The most common way to perform a function is to have a universal format of documenting a site's operational procedures. The system's operations should be formally documented starting from the initial startup (i.e., beginning of a shift) all the way through to the last task needed to close down the process. This is another sub-component that is required for traceability, repeatability, consistency, and overall reliability. The SOP is typically the main overarching process in which a practitioner will use from start to finish to setup, perform, and complete the inspection. This SOP is a highly detailed set of instructions which removes any unnecessary variation between operators. This SOP is also the main point of reference to which all the other sub-components are linked. The SOP should be detailed enough that there is little room for operator error between steps and that all the quality controls are met continuously. The setup, technique, settings, equipment, quality controls, and personnel should all be collectively organized and systematically monitored to ensure conformance within the SOP. Every step within the process should be included such as: what personnel are required, how to setup the critical equipment for the given inspection, system warm up, verification using the masters or IQIs, correct handling of the inspection pieces, part placement, hardware and software settings, acquiring the data, processing the data, reviewing the data, dispositioning the product, segregation of good and bad parts, safety protocols, continuous

throughput, shutdown, and if any nonconformances arise during the application. Any and all of these parts may also break out into additional quality work instruction (QWI) if further details are needed to make the process easier for the operator to follow. A large factor in maintaining a SOP is ensuring proper configuration management by using revision numbers and dates in between each modification or change.

Quality Work Instructions

This type of work instruction typically includes a set of directions specific to a smaller amount of operator responsibilities. A QWI may be written just for loading and unloading of product into and out of the system. One could also make a QWI specific for the image interpretation requirements on what is acceptable and rejectable and how to make correct dispositions. Anytime additional specific instructions are needed, a QWI can be developed and added into the main SOP pending it does not cause conflicts or contradictions. Using QWIs can reduce confusion with having a large detailed SOP by breaking down the tasks into more manageable functions including preventative maintenance procedures or performing a requalification. Along with every other sub-component listed, it needs to be documented, referenced, maintained, and provided to the customer upon request.

CONCLUSIONS

The intention of this report was to provide additional detailed concepts and understanding on what information is reviewed during the oversight of an Army production site, specifically for nondestructive tests (NDT) inspections. For munitions or weapon systems that require NDT, specifically using radiographic inspections, the ASTM E 1742 specification must be followed. Although this ASTM document calls out several required sub-components, not many details are provided on what content is necessary. The personnel, equipment listing, operating procedures, technique documentation, qualification, and requalification plan are all reviewed in this report. This overview does not cover every situation, aspect, or applications, but does provide further knowledge on what should be provided to a customer prior to beginning any type of production work. The primary objective of performing this review is to ensure detailed documentation on process controls and practices are in place, the NDT personnel are certified correctly, and the specifications of the parts are met at every site.

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LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

ADR	Automated Defect Recognition
ARDEC	Army Research Development and Engineering Center
aSi	amorphous Silicon
ASNT	American Society of Nondestructive Testing
Be	Beryllium
c	centi-, 1E-2
CNR	Contrast to Noise Ratio
CR	Computed Radiography
CT	Computed Tomography
Cu	Copper
dB	Decibel
DDA	Digital Detector Array
eV	electron Volt
IOP	Internal Operating Procedure
ISO	International Standards Organization
k	kilo-, 1E3
Lp/mm	Line pairs per millimeter
M	Mega-, 1E6
m	meter
mm	milli-meter, 1E-3
min	minute
MTF	Modular Transfer Function
NAS	National Aerospace Standard
NDE	Nondestructive Evaluation
NDI	Nondestructive Inspection
NDT	Nondestructive Testing
OTJ	On The Job
QWI	Quality Work Instructions
RQI	Representative Quality Indicator
RT	Radiographic Testing
SNR	Signal to Noise Ratio
SOP	Standard Operating Procedure
µ	micro-, 1E-6
W	Tungsten

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